# Recommendations on RFQ final tuning

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In a previous technical note, “Analysis on AccSys RFQ resonator model”, it was determined that the fundamental problem that prevents bringing the quadrupole field into a standard curve for tuning is the detuned output matcher. Unfortunately, the only way to fix the RFQ without affecting fields in the matching area is to implement the mechanical corrections indicated in that technical note.

It is understood that there is an additional distortion of the quadrupole field distribution due to the local frequency variation along the RFQ. This frequency variation is a serious problem as well, but it can be solved by proper RFQ assembly and tuning. This note studies the source of local frequency variation and gives recommendations on final tuning.

## Effect of vane tips modulation.

Very specific vane tip modulation (see Fig.1) attracted attention as a possible reason of the local frequency variation along RFQ.

To check whether the vane tip modulation affects local resonant frequency, one accelerating period with modulated vane tips (using parameters of modulation for cell #267, the high energy end of RFQ, see Fig.2) has been simulated. The frequency of the model was found to be 324.7 MHz, while the frequency of the same model with identical average bore radius and no modulation was 323.5 MHz. The difference of 1.2 MHz is significant and close to the estimation of 1.3 MHz made in previous note. This result indicates that the vane tip modulation increases local frequency and is a primary reason for its variation along RFQ. To

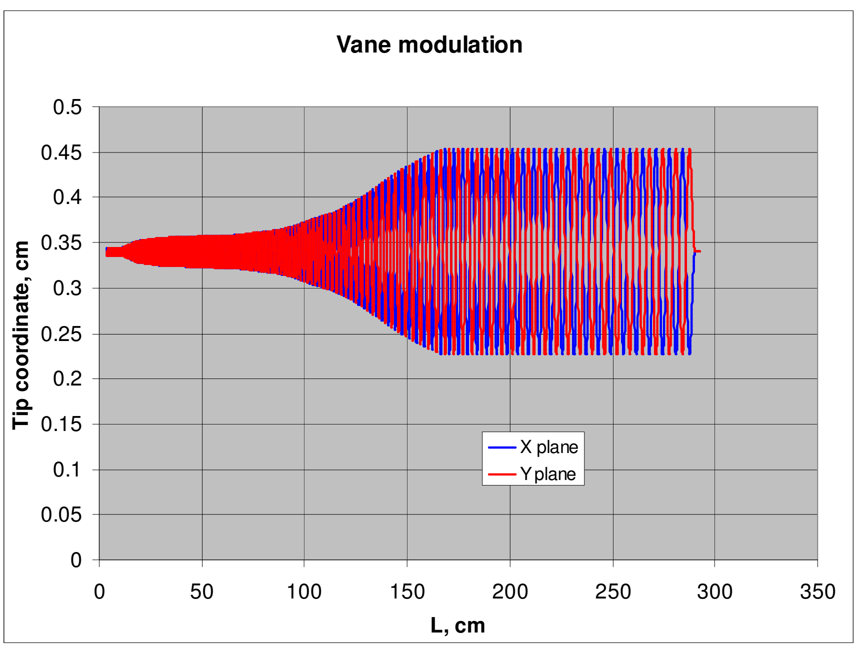


Fig. 1

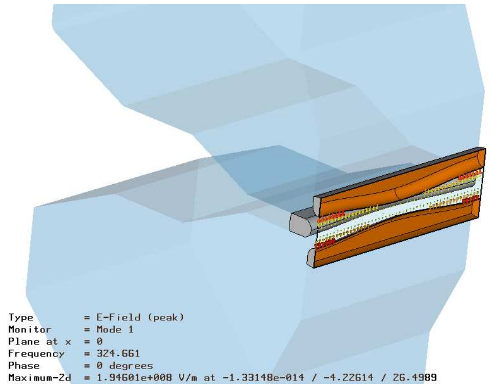


Fig. 2

validate this assumption completely, the full length 3D RFQ model with modulated vane tips has been simulated.

**<u>RFQ 3D model with vane tips modulation</u>**

The bases of the 3D RF model prepared for simulation were a solid model of RFQ univane developed by AccSys, some technical drawings of RFQ parts, and mechanical measurements of actual dimensions of the cut-backs: 56.2 mm for the input end and 59.8 mm for the output end. In the 3D model, the end-wall tuners were set to a default value of 1.00" of penetration as it was during the initial RF measurements. The tuning slugs had no penetration into the cavity at that time; therefore, the tuning slugs in the 3D model were set flush with the inner wall of the RFQ cavity to simulate initial measurements.

The modulation of the vanes in the 3D model is in accordance with Fermilab Specification 5500-ES-371026 and based on the same table that was used for tool-path table preparation. The complete 3D model is shown in Fig.3. The simulation was performed using HFSS.

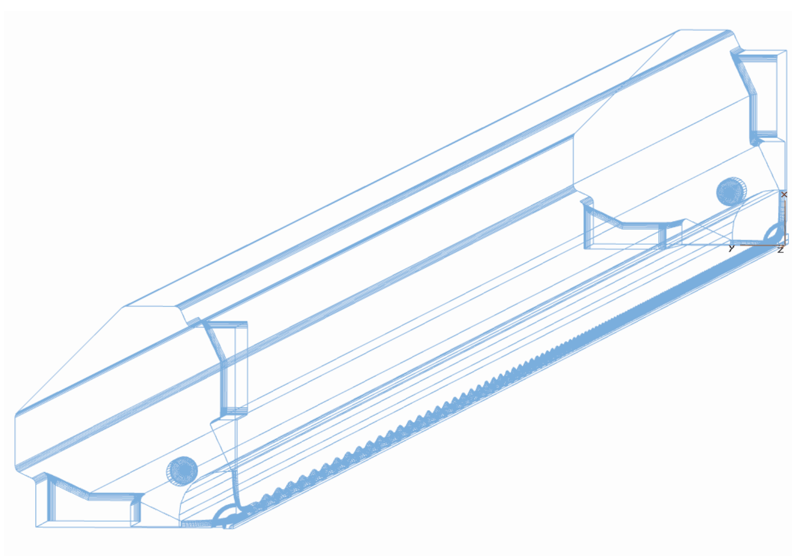

Fig. 3

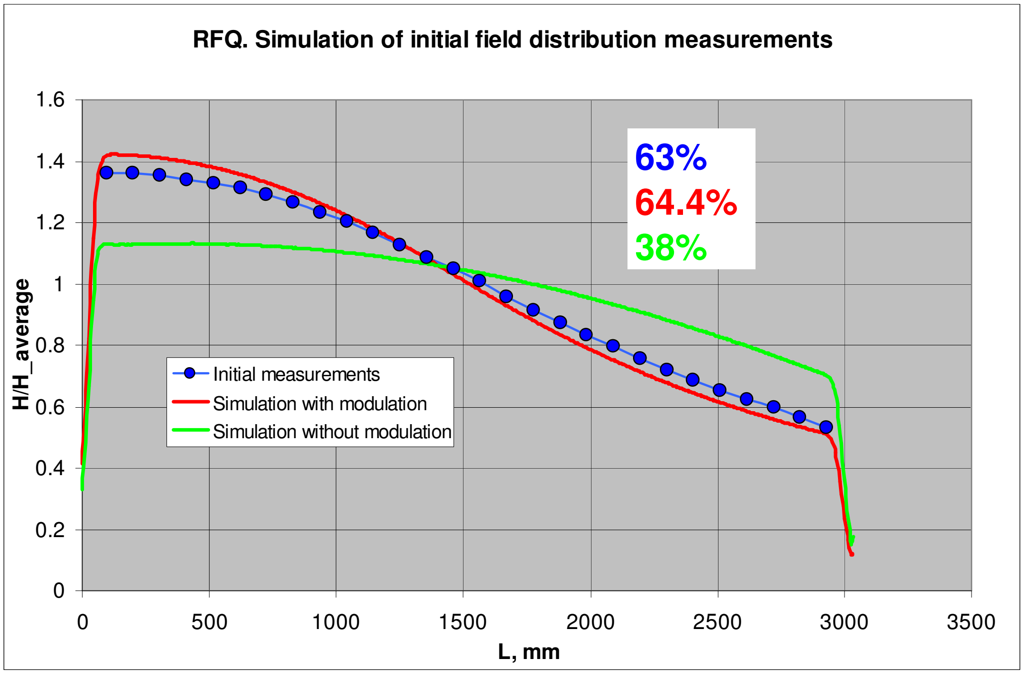

Fig. 4

## Results

Fig. 4 shows the field distributions as simulated with and without vane modulation in comparison to the previous actual measurements. With the vane tip modulation included in the model, the simulation reproduces the measurements with high accuracy, including both total field distribution tilt and sinus-like shape. Therefore, the theory that the vane tip modulation is responsible for the additional field distribution distortion is supported.

Without modulation, the field tilt in the simulation is ≈40%, due only to the detuned output matcher. This is an ideal case with a "perfectly tuned" RFQ body and no frequency error due to vane modulation. It represents, therefore, the minimal field tilt that can be achieved at the specified 325 MHz frequency with the original cut-back dimensions. There is no way to improve the field distribution and maintain the correct frequency without fixing output matcher (actually this was realized empirically during attempts to tune the RFQ using only the slug and end-wall tuners).

## RFQ final tuning

After increasing the vane cut-back at the high energy end to the dimensions recommended in our previous technical note, the final tuning can be done with the slug tuners.

To check final RFQ tuning in the simulation, the output matcher cut-back dimensions in the solid model were set to the specified values and slug tuners were introduced. Drawings of slug tuners were not available, so it was assumed that the slug tuners are simple cylinders with diameter of 25.4 mm. The locations of the slug tuners along RFQ were determined from the AccSys univane solid model. The end-wall tuners were set to a default value of 1.00" of penetration and were not used in final tuning.

The quarter of the resulting solid model is shown in Fig.5:

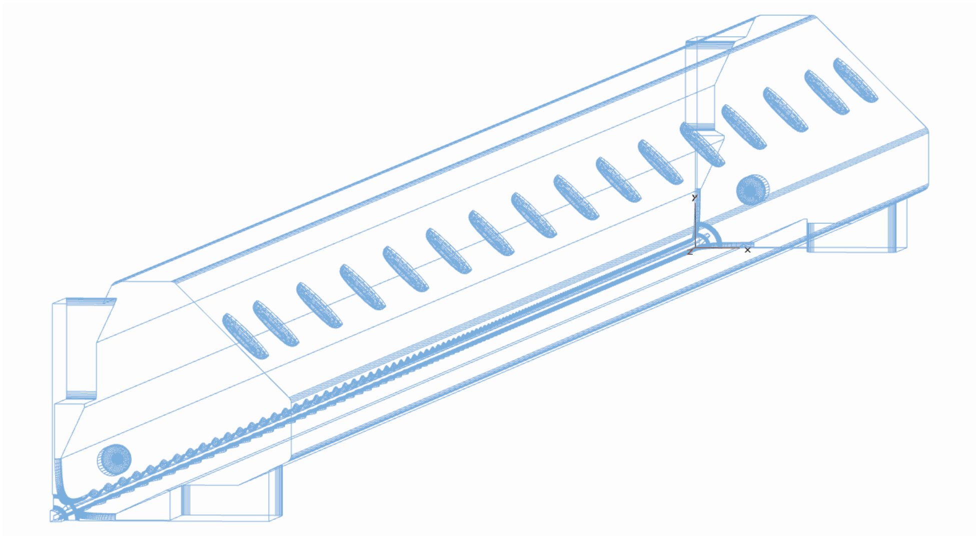

Fig.5

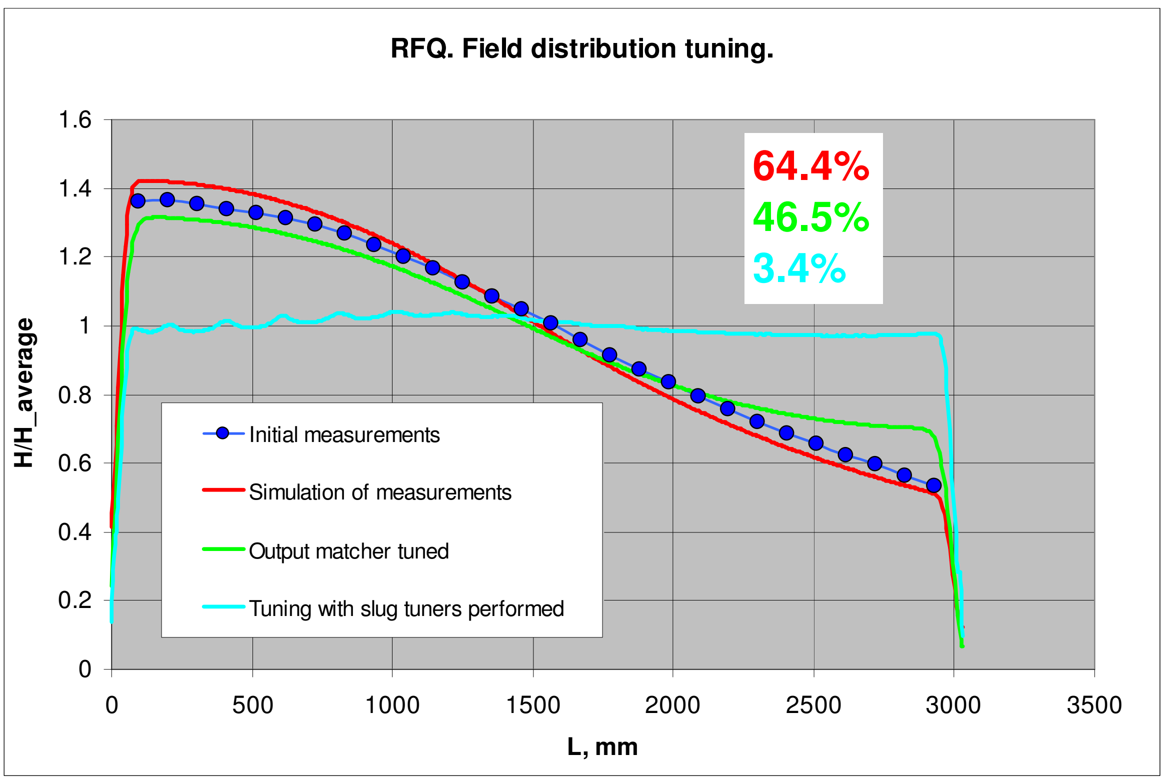


Fig.6

Skipping intermediate simulations of the tuning process with slug tuners, the result is summarized in Fig. 6. We can conclude that the proper output cut-back dimensions along with fine tuning with slug tuners can solve the problem of field flattening completely. The small bumps at the low-energy end are due to the slug tuners as explained in the previous note. The final penetrations of slug tuners as simulated are given in Table 1.

Table 1

| Tuner # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration,mm | 20 | 20 | 20 | 20 | 16 | 12 | 8 | 8 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |

At this point it does not make sense to pursue field flatness in the simulations to the required level of less than 2%. The table is intended just to give a feeling for the right tuner strokes. The real tuner penetrations required will depend strongly on actual univane assembly and alignment. And here we have to solve one more problem.

The slug tuners can only increase the local and overall frequency. After field flattening in the simulation, the RFQ frequency, shown in Fig. 7, is well above required value of 325 MHz.

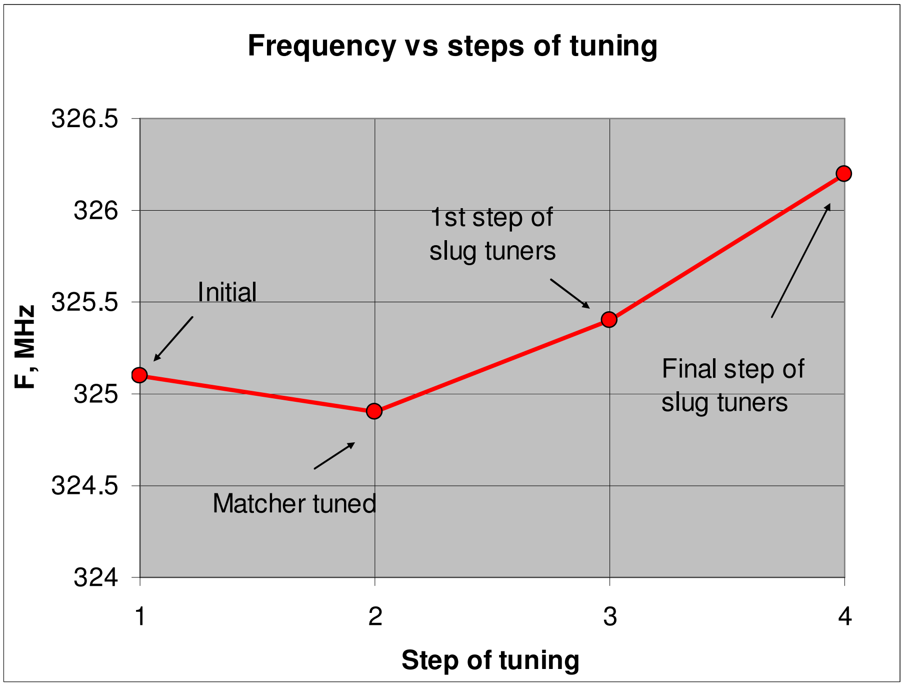


Fig.7.

The initial RFQ frequency as measured at ACCSYS was 324.9 MHz. This is lower than that of the simulations, but still not low enough. A safe margin indicates an initial frequency of about 323.5 MHz.

The most effective and simplest way to decrease the initial frequency of the resonator is to reduce the average bore radius by 50-70 μm. This can be done during assembly with the use of thinner shims and gap gauges of smaller diameter. In test simulations, reducing the average bore radius by 50 μm decreased final overall frequency from 326.2 MHz to 324.8 MHz in the tuned model. Therefore the sensitivity of overall frequency to the average bore radius is 0.028 MHz/μm for 3D model with modulated vanes. This is in a good agreement with 0.027 MHz/μm obtained from the MWS cross-section model.

## Summary

Simulation of a 3D RFQ model including the actual vane modulation shows that the modulation has a significant impact on the frequency of the structure and explains the local frequency error suggested in the previous note. Results of this complete simulation are in excellent agreement with the measurements made on the RFQ during initial assembly and tuning.

The simulations also show that tuning the RFQ for flat field distribution with the slug tuners is possible once the previously recommended cut-back correction is done. To obtain the correct final frequency, the average vane spacing must be adjusted for a sufficiently low structure frequency prior to field flattening and fine tuning with the slugs.